Geochemistry & Mineral Potent

by *Stephen J. Reynolds,* Geologist
Arizona Bureau of Geology and Mineral Technology
and
Stanley B. Keith, Consulting Geologist, Tucson

Editor's Note: This article represents the first in a series of research reports about specific aspects of the geology and mineral resources of Arizona. These technical papers are intended to convey results of research conducted by Bureau geologists. Each article in this series will be preceded by a nontechnical summary that highlights the most important conclusions.

NONTECHNICAL SUMMARY

Peraluminous granitic rocks (granitoids) are characterized by relatively high contents of aluminum as compared to potassium, sodium, and calcium. These granites are distinctive because they contain aluminum-rich minerals such as muscovite and garnet, and appear to have been derived from the melting of crustal rocks. This paper presents a system for classifying peraluminous granites that has important implications for mineral exploration. For example, most peraluminous granites in Arizona are less favorable for certain types of mineral deposits (such as molybdenum, beryllium, tin, and uranium) than are similar granites of Europe and Thailand. These differences in mineral potential are probably due to regional variations in tectonic setting and composition of the crustal source rocks.

PERALUMINOUS AND METALUMINOUS GRANITOIDS

In the past decade, geologists have become increasingly aware that granitic rocks (granitoids) can be subdivided into several types on the basis of mineralogy and chemical composition. One important criterion for classification of granitoids involves the molecular ratio of $Al_2O_3/CaO+Na_2O+K_2O$ (abbreviated as A/CNK). Granitic rocks are classified as *peraluminous* if this ratio is greater than one, and *metaluminous* if the ratio is less than one* (Shand, 1927). Granitoids that have A/CNK ratios greater than or equal to 1.1 can be considered strongly peraluminous. The differences in chemical composition between metaluminous, weakly peraluminous, and strongly peraluminous granitoids are manifested by differences in mineralogy. Metaluminous granitoids, excluding the more felsic varieties, commonly contain amphibole or pyroxene and accessory sphene. Felsic metaluminous and weakly peraluminous granitoids typically contain some mica, usually biotite. In contrast, strongly peraluminous granitoids are characterized by aluminum-rich minerals such as muscovite, garnet, and cordierite, and by well-developed pegmatitic, alaskitic, and aplitic phases.

Based on an extensive compilation of chemical analyses of igneous rocks from around the world, we conclude that granitoids can be subdivided into two fundamental suites based on aluminum saturation:

1) Metaluminous granitoid suite. These form compositionally broad differentiation series that may span the entire range in lithology from metaluminous gabbro or diorite to granite. Some of the most differentiated end members of this series are weakly peraluminous (A/CNK=1.0–1.1).

2) Strongly peraluminous granitoid suite. These have A/CNK ratios $>$ 1.1, are more compositionally restricted, and are not part of a differentiation series that includes low-silica phases.

Similar classifications of granitoids have been discussed by other authors (Chappell and White, 1974; Miller and Engels, 1975; and Pitcher, 1979). In this paper, we will concentrate on the geochemistry and mineral potential of the strongly peraluminous granitoid suite (referred to in the remainder of this article as peraluminous granitoids).

DISTRIBUTION AND AGE OF PERALUMINOUS GRANITOIDS

Peraluminous granitoids are present throughout much of the world, but are less common than metaluminous granitoids. Some of the best known occurrences of peraluminous granitic rocks are in the Lachlan mobile belt of eastern Australia, the Hercynian orogen of Europe, and the Himalayan Mountain belt of southern Asia. In the western U.S., peraluminous granitoids occur in a broad, discontinuous belt that extends southward from northeastern Washington state through Idaho, eastern Nevada, southeastern California, and southern Arizona (Miller and Bradfish, 1980; Keith and Reynolds, 1980). Peraluminous granites are known to occur in at least 20 mountain ranges in Arizona, with especially large exposures of granite being present in the Santa Catalina and Rincon Mountains near Tucson.

Post-Precambrian peraluminous granitoids of the western U.S. can be subdivided into three age groups: Jurassic, middle Cretaceous to early Tertiary, and middle Tertiary. Peraluminous granitoids of Jurassic age are mostly found in eastern Nevada, whereas middle Cretaceous to early Tertiary granitoids, by far the most abundant age group, occur throughout the entire granitic belt. Middle Tertiary peraluminous granites, the youngest age group, are presently known to occur only in southern Idaho and eastern Nevada.

GEOCHEMISTRY AND MINERAL POTENTIAL

Granitic rocks can be peraluminous for several reasons. Some granitoids are peraluminous due to genuinely high aluminum contents which result in correspondingly high A/CNK ratios. Other granites are peraluminous simply by virtue of low combined contents of potassium, sodium, and calcium. Examination of geochemical analyses for strongly peraluminous granitoids from around the world indicates that

***Igneous rocks with Al_2O_3/Na_2O+K_2O ratios less than one are classified as peralkaline.**

ial of Peraluminous Granitoids

few sweeping generalizations can be made regarding typical contents of Al, K, Na or Ca. Instead, there are significant regional variations in geochemistry of peraluminous granites (Table 1). In order to more fully understand these geochemical differences, we have explored various criteria for classifying peraluminous granitoids because the granitoids have too limited a compositional range to use traditional classification techniques (i.e., Peacock, 1931). Accordingly, we have developed a classification system that does not require a broad compositional spread for a single peraluminous granitic suite. To arrive at this classification system, we have compiled an extensive geochemical data base on metaluminous igneous suites of known alkalinity (e.g., calcic, calc-alkalic, alkalic-calcic, and alkalic). We have

Table 1. Representative chemical analyses of peraluminous granites.*

Location	Al_2O_3	CaO	Na_2O	K_2O
Santa Catalina Mts., Arizona	14.6	1.6	4.1	3.7
Whipple Mts., California	15.0	2.2	4.1	3.4
Ruby Mts., Nevada	13.8	1.1	3.4	4.5
Northeastern Washington	14.5	1.4	3.2	4.7
Southern Nova Scotia	15.4	0.8	3.6	4.0
Central Portugal (Hercynian)	15.3	0.8	3.5	5.4
Armorican Massif, France (Hercynian)	14.6	0.6	3.7	4.8
Schwarzwald, West Germany (Hercynian)	15.1	0.4	3.1	5.2
Higher Himalaya, Nepal	14.7	0.5	4.1	4.5
Ku Long, Thailand	13.9	1.0	2.7	5.1
Hub Kapong, Thailand	13.3	1.4	2.4	5.3
Kosciusko Batholith, Australia	13.2	1.8	2.6	3.8

*All analyses contain approximately 72 to 73 percent silica. Note that granites from Arizona and California have more calcium and less potassium than granites from Thailand or Europe that are famous for their associated mineral deposits.

found that a subalkaline-alkaline boundary, which approximately coincides with the calc-alkalic-alkali-calcic boundary of Peacock (1931), can be tightly constrained on variation diagrams that plot SiO_2 versus CaO or SiO_2 versus K_2O–CaO (Figures 1 and 2). Such diagrams can be used to evaluate the alkalinity of even the most compositionally restricted peraluminous suites (Figures 3 and 4). Based on these diagrams, peraluminous granitoids can be subdivided into three general catagories: alkaline, marginally alkaline, and subalkaline. Granitoids that plot within the alkaline field on the diagrams are rich in K_2O, poor in CaO or both. They also have relatively low contents of FeO, MgO, and TiO_2. In contrast, subalkaline peraluminous granitoids have less K_2O and more CaO, FeO, MgO, and TiO_2. Marginally alkaline granitoids plot along the subalkaline-alkaline boundary and have intermediate contents of K_2O and CaO.

This subalkaline-alkaline distinction has important applications for the exploration of mineral deposits in both peraluminous and metaluminous granitoids. In general, granitoids that plot within the alkaline field have higher contents of lithophile elements (K, Rb, Li, Be, Mo, Sn, U, and Th) than granitoids that plot within

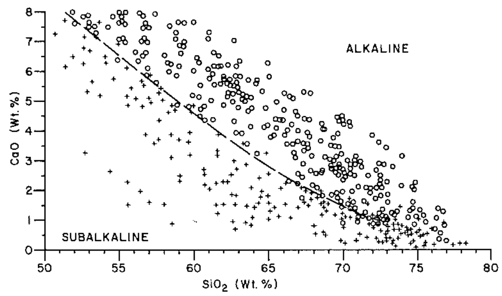

Figure 1. SiO_2 versus CaO variation diagram for metaluminous-suite igneous rocks of known alkalinity. Dots represent calc-alkalic and calcic rocks; crosses indicate alkali-calcic and alkalic rocks (classifications according to Peacock, 1931).

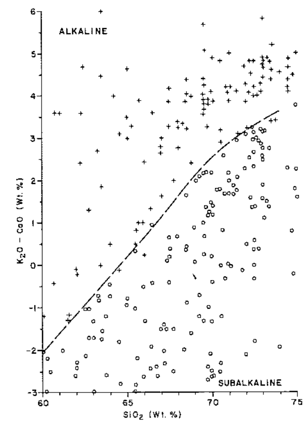

Figure 2. SiO_2 versus K_2O minus CaO variation diagram for metaluminous-suite igneous rocks of known alkalinity. Symbols same as Figure 1.

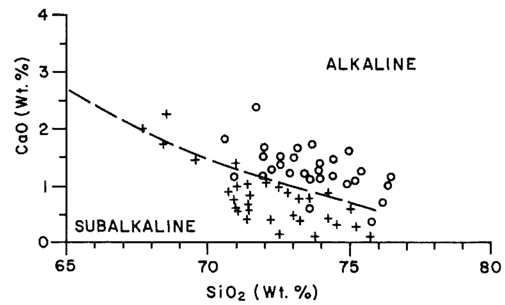

Figure 3. SiO_2 versus CaO variation diagram for peraluminous granitoids of Arizona (o) and the Hercynian belt of Europe (+).

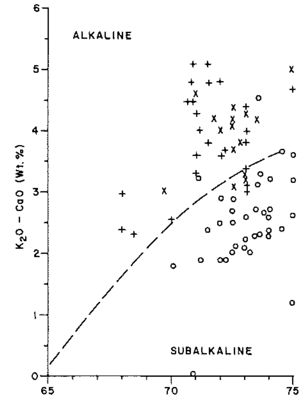

Figure 4. SiO_2 versus K_2O minus CaO variation diagram for peraluminous granitoids of Arizona (o), Europe (+), and Thailand (x).